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(54) MITIGATING LNG BOILOFF BY APPLICATION OF PELTIER COOLING

(57) An apparatus includes a cryogenic tank disposed within an insulation tank such that an annulus is formed therebetween. The apparatus also includes a first heat transfer element configured to absorb heat from the cryogenic tank and a second heat transfer element configured to discharge heat into an ambient region proximate the insulation tank. The apparatus has legs between the first heat transfer element and the second heat transfer element, and an energy source configured to provide a heat flux through the legs.

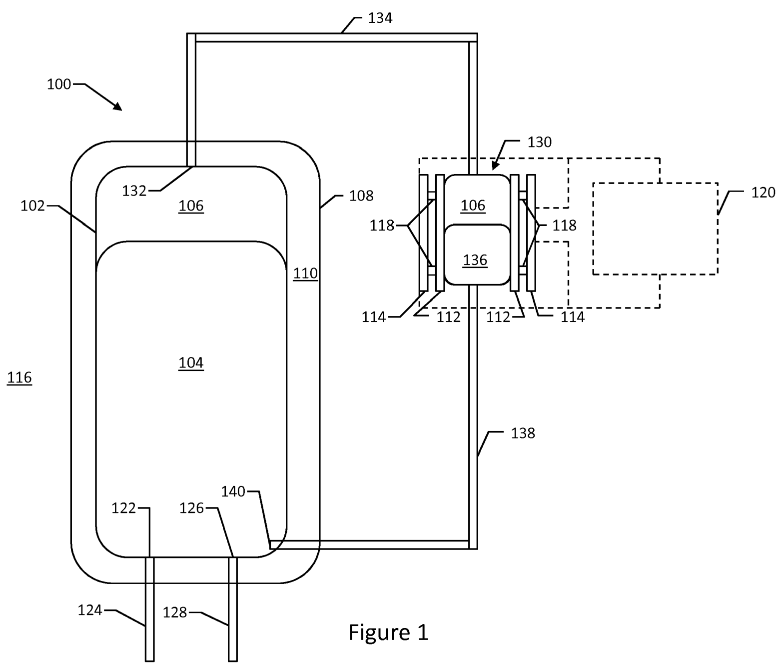

Figure 1

EP 3 181 986 A1

Description

FIELD OF THE INVENTION

[0001] The invention relates to apparatus for mitigating gas formed by heat entering cryogenic liquid in storage.

BACKGROUND

[0002] Liquid Natural Gas or Liquefied Natural Gas (LNG) is an increasingly popular clean fuel. In some locations, it is used as fuel for transport. In other words, vendors at fuel stations provide LNG to customers for use in commercial, fleet, or personal vehicles. However, the storage of LNG at the fuel stations may currently suffer some deficiencies. Specifically, heat from the environment tends to find its way into the LNG, causing the LNG to change to a gas form, increasing pressure in the container. Historically, efforts to mitigate this problem have involved improvements in insulation/tank technology. Current LNG storage tanks for fuel stations are generally double-wall vacuum insulated tanks, sometimes called "thermos flasks." However, the current limit for such tanks is approximately 15 W/m^2 heat flux with about 200°C temperature difference between the LNG and the environment. Significant reductions to the heat ingress through improved insulation are generally thought to be very cost inefficient. Moreover, it is thought to be effectively impossible to eliminate the heat leak completely. Thus, the pressure in the containers will have a tendency to rise during prolonged periods of storage.

[0003] Other attempts to solve the problem of heat ingress involve venting or flaring of the gas. While such solution might be acceptable in some applications, such as emergency safety release, it is generally thought to be undesirable in a fuel station environment.

[0004] In some instances, a customer is available to purchase the gas formed by the warming of the LNG. However, customers may not be available, particularly at remote storage locations.

[0005] In other circumstances, a refrigeration system using liquid nitrogen (-196°C) cools the gas below the dew point (-163°C). Such refrigeration involves an external circuit to exchange heat via a heat exchanger. However, such refrigeration systems and other conventional cooling technology can be complex and difficult to maintain. For example, at storage locations, with liquid nitrogen or other refrigerant loops, periodical replenishment of spent liquid refrigerant may be required. Similarly, when LNG is transferred in industrial applications (e.g., from a floating LNG production facility to an LNG carrier), the gas (called "boiloff LNG") may require a separate conduit to return the gas to the liquefaction unit and prevent excess pressure buildup.

[0006] Thus, there is a desire to provide for alternative mitigation of heat uptake by the LNG.

SUMMARY

[0007] An apparatus includes a cryogenic tank disposed within an insulation tank such that an annulus is formed therebetween. The apparatus also includes a first heat transfer element configured to absorb heat from the cryogenic tank and a second heat transfer element configured to discharge heat into an ambient region proximate the insulation tank. The apparatus has legs between the first heat transfer element and the second heat transfer element, and an energy source configured to provide a heat flux through the legs.

BRIEF DESCRIPTION OF THE FIGURES

[0008]

Figure 1 is a schematic illustration of an exemplary apparatus in accordance with the present disclosure.

Figure 2 is a schematic illustration of another exemplary apparatus in accordance with the present disclosure.

Figure 3 is a schematic illustration of yet another exemplary apparatus in accordance with the present disclosure.

Figure 4 is a schematic illustration of still another exemplary apparatus in accordance with the present disclosure.

DETAILED DESCRIPTION

[0009] Referring now to the figures, apparatus 100 as illustrated includes a cryogenic tank 102 having cryogenic liquid 104 and cryogenic gas 106 therein. The cryogenic tank 102 is disposed within an insulation tank 108 with an annulus 110 formed between the cryogenic tank 102 and the insulation tank 108.

[0010] In certain applications, such as LNG storage, it is desirable to maximize the amount of cryogenic liquid 104 and minimize the amount of cryogenic gas 106. This may be accomplished by either preventing cryogenic liquid 104 from becoming cryogenic gas 106 (e.g., by maintaining the cryogenic liquid 104 at a sufficiently cold temperature to prevent boiloff), or by converting cryogenic gas 106 into cryogenic liquid 104 in a process known as reliquification. Both of these options require cooling. Thus, the apparatus 100 includes a first heat transfer element 112 configured to absorb heat from the cryogenic tank 102 and a second heat transfer element 114 configured to discharge heat into an ambient region 116 proximate the insulation tank 108. Legs 118 may provide communication between the first heat transfer element 112 and the second heat transfer element 114. Thus, heat may be extracted from the contents of the cryogenic tank 102 via the first heat transfer element 112 before flowing through the legs 118 and into the second heat transfer element 114 and ultimately into the ambient region 116. The transfer of heat from the contents of the cryogenic tank 102 to the ambient region 116 utilizes an energy source 120 configured to provide a heat flux through the legs 118. The use of the first heat transfer element 114 and the second heat transfer element 116 may provide advantages over other methods of cooling. For example, gas and vapor cooling cycles require moving parts that can be susceptible to breakdown absent regular maintenance. Similarly, these cooling cycles may result in undesirable emissions and/or the need for refills of the coolant. Additionally, the cooling may be easily adjusted by merely changing the input voltage or current.

[0011] The cryogenic tank 102 may be a fluid-tight tank with a loading port 122 and corresponding loading conduit 124 to allow for the introduction of cryogenic liquid 104 into the cryogenic tank 102 from an external source. For example, in the case of the cryogenic tank 102 being a fuel tank, and more specifically an LNG fuel storage tank, the loading port 122 may allow for the inflow of LNG from a pipeline, a tanker truck, or upstream or intermediate storage equipment. Similarly, the cryogenic tank 102 is shown with an unloading port 126 and unloading conduit 128 to allow the cryogenic liquid 104 to exit the cryogenic tank 102 for use by a consumer or other entity. For example, in the case of cryogenic liquid 104 being a fuel, the outlet 124 may allow for the cryogenic liquid 104 to leave the cryogenic tank 102 for use in cars, trucks, mobile power generators, 'peak shavers,' or other vehicles. Notably, while a distinct loading port 122, loading conduit 124, unloading port 126, and unloading conduit 128 are illustrated, the loading port 122 and unloading port 126 could be combined or other modifications could be made with appropriate valves and conduits. Additionally, while the loading port 122 and the unloading port 126 are illustrated at a bottom of the cryogenic tank 102, the location may be modified as appropriate.

[0012] When used for LNG storage, the cryogenic tank 102 may have dimensions appropriate for the site and the turnover expected. For example, a storage location may have one or more cryogenic tanks 102 having a size of from about 25 m^3 to about 40 m^3.

[0013] The cryogenic liquid 104 may be LNG or other cryogenic fuels, for example. Accordingly, the cryogenic gas 106 may be boiloff gas from the cryogenic liquid 104. Alternatively, the cryogenic gas 106 may be present at introduction of fluid into the cryogenic tank 102. Notably, however, the gas present at the introduction of fluid into the cryogenic tank 102 may not be cryogenic gas 106. In LNG applications, the cryogenic liquid 104 and the cryogenic gas 106 may have a temperature of about -162°C , if at atmospheric pressure. However, the exact temperatures may vary with pressure, as is known in the art.

[0014] The insulation tank 108 may be a fluid-tight tank that surrounds the cryogenic tank 102 with passages for the conduit(s) associated with the port(s) of the cryogenic tank 102.

[0015] The annulus 110 between the cryogenic tank 102 and the insulation tank 108 may be a vacuum. In order to provide the most efficient insulation, the annulus 110 may also include gasses such as argon and/or carbon dioxide and/or urethane foams. Multi-layer insulation, such as those available from Technifab Products of Brazil, Indiana, may also be effective for cryogenic applications.

[0016] The first heat transfer element 112 and the second heat transfer element 114 may both be part of a thermoelectric cooler such as a Peltier cooler. Alternatively, heat transfer elements 112 and 114 may be elements of a Thomson cooler or other cooler with similar advantages. While shown as being on sides of respective vessels, the first heat transfer element 112 and the second heat transfer element 114 may be on top and bottom or otherwise situated about the vessels they are designed to cool. As illustrated, the first heat transfer element 112 and the second heat transfer element 114 are plates. However, other shapes and configurations may also be used as appropriate. The first heat transfer element 112 may be considered a "cold" side as it absorbs heat from the environment. Specifically, the first heat transfer element 112 absorbs heat from the cryogenic liquid 104 and/or the cryogenic gas 106. As will be further discussed below, the first heat transfer element 112 may be in contact with the cryogenic tank 102 or may otherwise provide cooling. The second heat transfer element 114 may be considered a "hot" side as it radiates heat into the environment. Specifically, the second heat transfer element 114 radiates heat into the ambient region 116.

[0017] The ambient region 116 is generally the environment external to the apparatus 100. For example, the ambient region 116 may be at about 23 °C when the ambient region 116 is the earth surrounding the apparatus 100 when it is underground. Alternatively, the ambient region 116 may have a more variable temperature when apparatus 110 is above ground or exposed to different conditions (e.g., such as on a ship).

[0018] The legs 118 may be semiconductors that transfer heat when a DC current flows as described below with respect to the particular figures.

[0019] The energy source 120 may be a conventional source or may include a clean energy source. Thus, the apparatus 100 may operate independent of a traditional power grid. More specifically, the energy source 120 may include a renewable, environmentally friendly, or other "green" energy source. For example, the energy source 120 may include one or more solar panels in the vicinity of the rest of the apparatus 100. Solar cells may be particularly useful because they would tend to provide more power when there is more cooling demand. Stated otherwise, the presence of sunshine would provide more energy (intensity and/or duration) for cooling at the times that there is more cooling demand because of warming of the ambient region 116 by the same sunshine.

[0020] Referring now specifically to Figure 1, in one embodiment, a reliquefication vessel 130 is provided external to the insulation tank 108. The reliquification vessel 130 may serve to convert cryogenic gas 106 from the cryogenic tank 102 into cryogenic liquid 104 which may be reintroduced into the cryogenic tank 102. In the illustrated embodiment, cryogenic gas 106 exits the cryogenic tank 102 via cryogenic gas outlet 132, passes through cryogenic gas conduit 134 which is configured to move the cryogenic gas 106 from the cryogenic tank 102 to the reliquefication vessel 130. The cryogenic gas 106 may then enter reliquefication vessel 130 where the first heat transfer elements 112 are in contact with the reliquefication vessel 130 and extract heat as described above. As heat is extracted, the cryogenic gas 106 may cool. Sufficient cooling may cause the cryogenic gas 106 to condense and become reliquified cryogenic liquid 136. The reliquified cryogenic liquid 136 may then pass through a reliquified liquid conduit 138 which is configured to move the reliquified cryogenic liquid 136 from the reliquefication vessel 130 to the cryogenic tank 102. The reliquified cryogenic liquid 136 may then pass through a reliquified liquid inlet 140 and into the cryogenic tank 102. As indicated above, the various inlets, outlets and conduits may be combined or modified to provide the functionality in a suitable manner.

[0021] Referring now to Figure 2, instead of being associated with a separate reliquefication vessel and being remote from the cryogenic tank 102 as shown in Figure 1, the first heat transfer element 112 may contact the cryogenic tank 102, either directly (not shown) or otherwise. For example, as illustrated, a secondary insulation tank 142 may encapsulate or otherwise be disposed about the insulation tank 108 such that a secondary annulus 144 formed between the insulation tank 108 and the secondary insulation tank 142. The secondary insulation tank 142 may provide further insulation between the cryogenic liquid 104 and the ambient region 116. For example, the temperature in the secondary annulus 144 may be about -50°C.

[0022] The first heat transfer element 112 may be disposed partly or entirely within the secondary annulus 144 such that heat present at or near the insulation tank 108 may be moved toward the ambient region 116. To effectuate such transfer, the second heat transfer element 114 may lie at or near a border between the secondary annulus 144 and the ambient region 116. Notably, while the first heat transfer element 112 and the second heat transfer element 144 are both shown as lying within the secondary annulus 144 and at a border thereof, modifications might move those elements inward or outward with respect to the secondary annulus 144. Similarly, while 2 sets of elements are shown, any number of element sets might be used. For example, the heat transfer elements might be sleeve-like structures that circumvent the appropriate tank.The secondary annulus 144 between the insulation tank 108 and the secondary insulation tank 142 may be a vacuum.

[0023] In the embodiment illustrated in Figure 2, instead of removing the cryogenic gas 106 for cooling and reliquification, the cooling occurs in situ. In such instance, there may be less cryogenic gas 106 formed and/or the cryogenic gas 106 may be reliquified directly back to cryogenic liquid 104 in the cryogenic tank 102.

[0024] Referring now to Figure 3, a few modifications are illustrated. On the right side of the illustration, an embodiment includes features from multiple embodiments above. For example, the reliquefication vessel 130 is present within the secondary insulation tank 142 which is still disposed about the inisulation tank 108 such that the secondary annulus 144 is formed therebetween. In this example, the reliquification vessel 130 is disposed within the secondary annulus 144 and only one set of heat transfer elements is shown for the reliquefication vessel 130. While any number of heat transfer elements could be included and in any number of locations, the illustration shows the first heat transfer element 112 being disposed within the secondary annulus 144.

[0025] On the left side of the illustration, an embodiment includes slightly modified features. Specifically, the reliquefication vessel 130 of the right side of the figure is absent and the conduits 134 and 138 are combined into a single conduit 146 in contact with the first heat transfer element 112. The remaining structures are similar to described above and are thus not described in detail. This figure illustrates that including some elements within others may provide for enhanced efficiency. More specifically, if the second heat transfer element 114 is in a relatively cooler location, maintaining the cryogenic liquid 104 in a liquid form may be achieved more efficiently.

[0026] Referring now to Figure 4, a more detailed illustration of an exemplary configuration of the cooling elements is provided. In this particular embodiment, the elements may form a thermoelectric cooler, sometimes referred to as a Peltier cooler. The legs 118 (shown as 118a and 118b in this figure) may be dissimilar semi-conductors or assemblies containing such semi-conductors, e.g. alloys of bismuth and tellurium. For example, leg 118a may be an n-type conductor and leg 118b may be a p-type conductor. The legs 118a and 118b may be positioned thermally in parallel and joined at one end by the first heat transfer element 112 and at the other end to the second heat transfer element 114. The first heat transfer element 112 may include a ceramic or other heat absorbing element 112a, an electrical insulator 112b, and a metal or other conductor 112c. The second heat transfer element 114 may include a ceramic or other heat dissipating element 114a, an electrical insulator 114b, and metal or other conductors 114c. A voltage may be applied to the conductors 114c of the second heat transfer element 114 (e.g., the heat dissipating side), resulting in a flow of electricity from the energy source 120, through electrical connector 148, and the legs 118a and 118b in series, through electrical connector 150 to complete the circuit. The flow of DC current across the junction of the two legs 118a and 118b may cause a temperature difference. As a result of the temperature difference, heat may be absorbed from the vicinity of the heat absorbing element 112a and moved to the heat dissipating element 114a. The heat may be carried from heat absorbing element 112a to heat dissipating element 114a by electron transport as electrons transport moves electrons from high to low energy state.

[0027] In other embodiments that are not illustrated, variants or combinations of the above-described embodiments might occur. For example, multiple pairs of first heat transfer elements 114 and second heat transfer elements 116 may be used, either in parallel or in a cascaded configuration. It is believed that a six stage device may attain cooling of -100°C from the outermost heat dissipating element 114a to the innermost heat absorbing element 112a. The cooling power of such device may be around 1 mW at -80°C without introducing vibration into the cryostat. In such embodiments, multiple pairs might be in a single location or the pairs might bridge across various walls of other elements. For example, one pair might lie in the annulus 110 while another lies in the secondary annulus 110.

[0028] Similarly, various embodiments show a single or multiple energy sources 120. However, the examples are not intended to be limiting and different configurations of the energy sources 120 may be used in parallel or in series with one or more pairs of heat transfer elements.

[0029] Various ports and conduits are illustrated to provide the ingress and egress of fluid. However, the illustrated embodiments should not be deemed limiting with respect to such configurations as modification for more or fewer ports and conduits may provide flexibility.

[0030] The sizing and placement of the heat transfer elements will depend on the cooling capacity desired. It is thought that between 7.5 W/m^2 and 15 W/m^2 of surface area is attainable. Preferably the cooling provided will be sufficient to substantially prevent boiloff of the cryogenic liquid 104 to create cryogenic gas 106. Alternatively, the cooling provided might be sufficient to reliquefy cryogenic gas 106 and create cryogenic liquid 104 once again.

[0031] The features described above could be used in conjunction with or as an alternative to conventional cooling technologies. Thus, in the case of storage locations such as fuel stations, the demand for nitrogen for cooling may be reduced or even eliminated. Similarly, in the case of LNG transfer, the boiloff lines could be made smaller or even eliminated, as could other liquefaction equipment.

Claims

1. An apparatus comprising:

a cryogenic tank disposed within an insulation tank such that an annulus is formed therebetween;
a first heat transfer element configured to absorb heat from the cryogenic tank; a second heat transfer element configured to discharge heat into an ambient region proximate the insulation tank;
legs between the first heat transfer element and the second heat transfer element; and an energy source configured to provide a heat flux through the legs.

2. The apparatus of claim 1, wherein the annulus comprises a vacuum.

3. The apparatus of claim 1, wherein the cryogenic tank is fluid-tight.

4. The apparatus of claim 1, wherein the first heat transfer element and the second heat transfer element each comprise a plate.

5. The apparatus of claim 1, wherein the energy source comprises a clean energy source.

6. The apparatus of claim 5, wherein the energy source comprises a renewable energy source.

7. The apparatus of claim 6, wherein the energy source comprises a solar panel.

8. The apparatus of claim 1, wherein the first heat transfer element contacts the cryogenic tank.

9. The apparatus of claim 1, wherein the first heat transfer element is remote from the cryogenic tank.

10. The apparatus of claim 1, further comprising:

a reliquefication vessel;
a cryogenic gas conduit configured to move cryogenic gas from the cryogenic tank to the reliquefication vessel; and
a reliquified liquid conduit configured to move reliquified cryogenic liquid from the reliquefication vessel to the cryogenic tank;
wherein the first heat transfer element is in contact with the reliquification vessel.

11. The apparatus of claim 1 further comprising a secondary insulation tank disposed about the insulation tank such that a secondary annulus is formed therebetween.

12. The apparatus of claim 11, wherein the first heat transfer element is disposed within the secondary annulus.

13. The apparatus of claim 10, further comprising a secondary insulation tank disposed about the insulation tank such that a secondary annulus is formed therebetween;

wherein the reliquefication vessel is disposed within the secondary annulus.

14. The apparatus of claim 13, wherein the first heat transfer element is disposed within the secondary annulus.

15. The apparatus of claim 1, wherein the legs comprise dissimilar semi-conductors.

16. The apparatus of claim 1, wherein the first heat transfer element comprises a ceramic heat absorbing element, an electrical insulator, and a metal conductor; and wherein the second heat transfer element comprises a ceramic heat dissiating element, an electrical insulator and conductors.

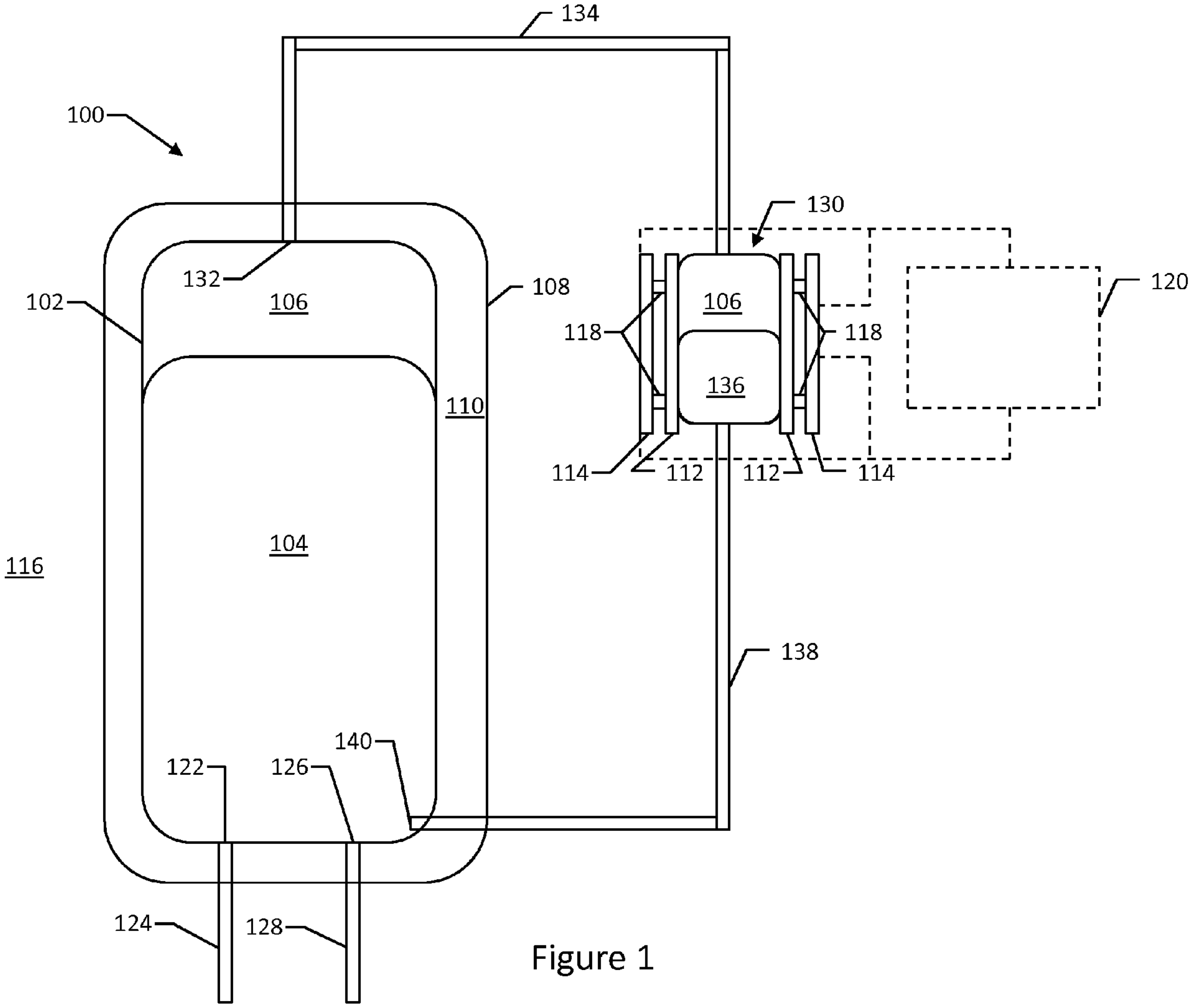
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Figure 1

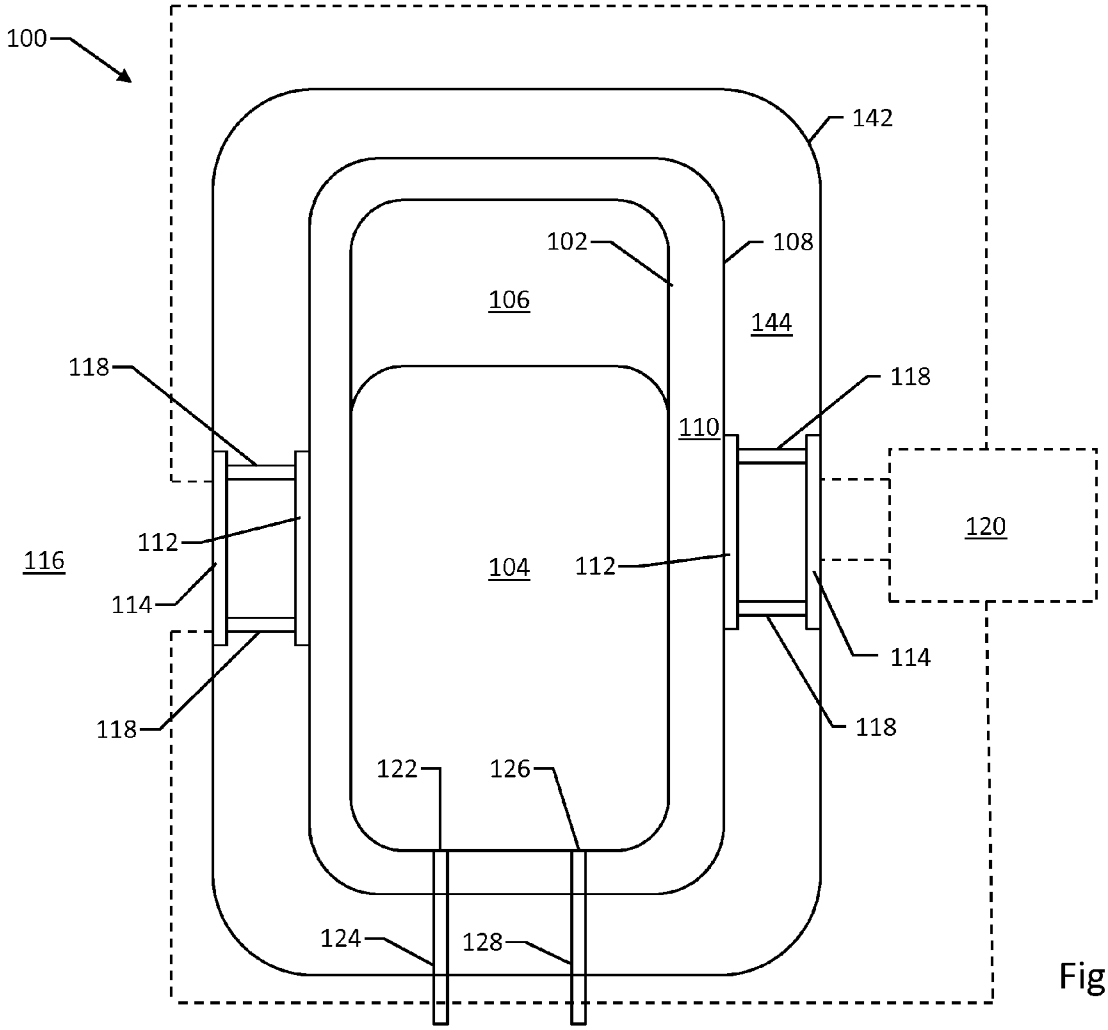
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Figure 2

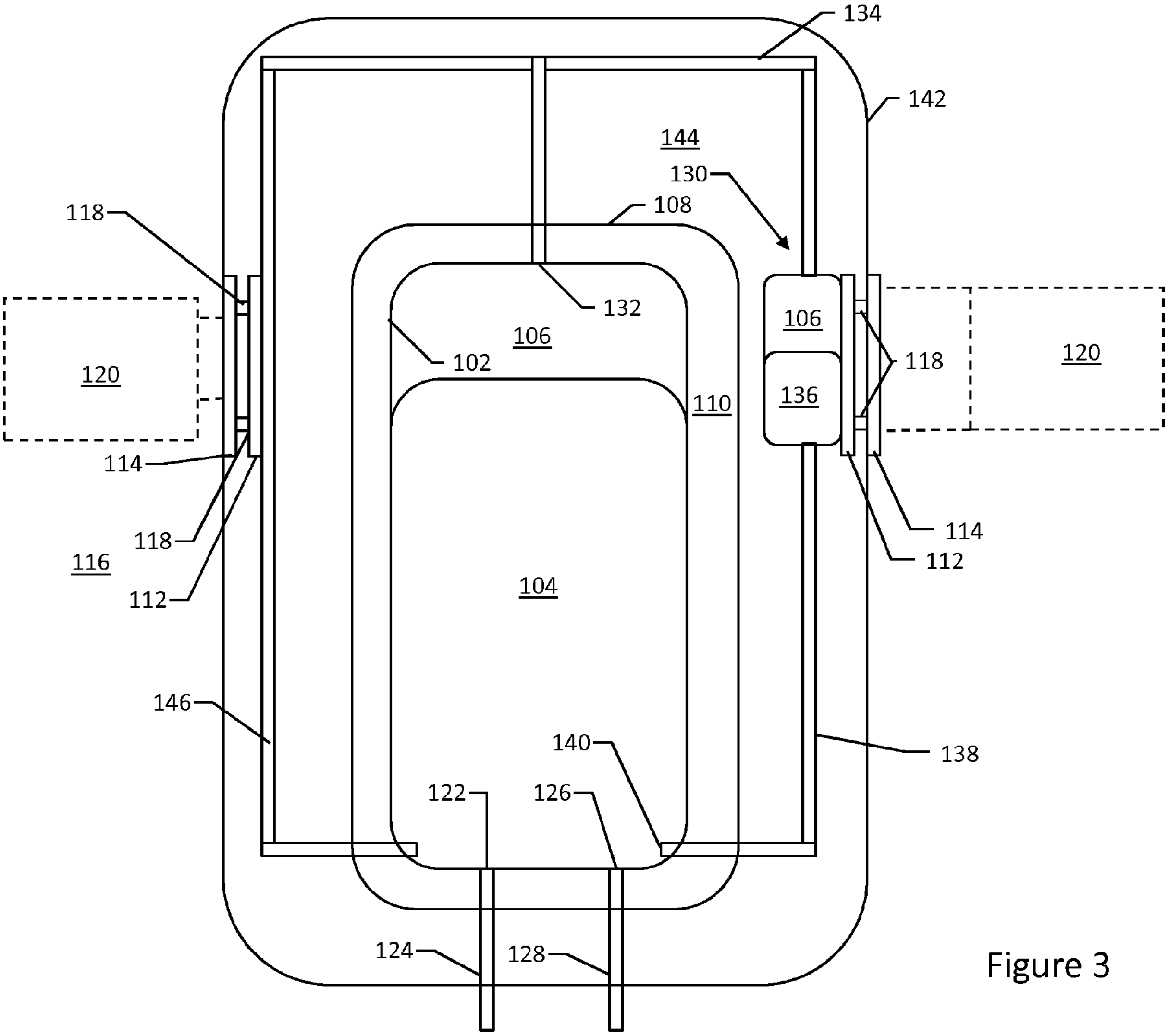
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Figure 3

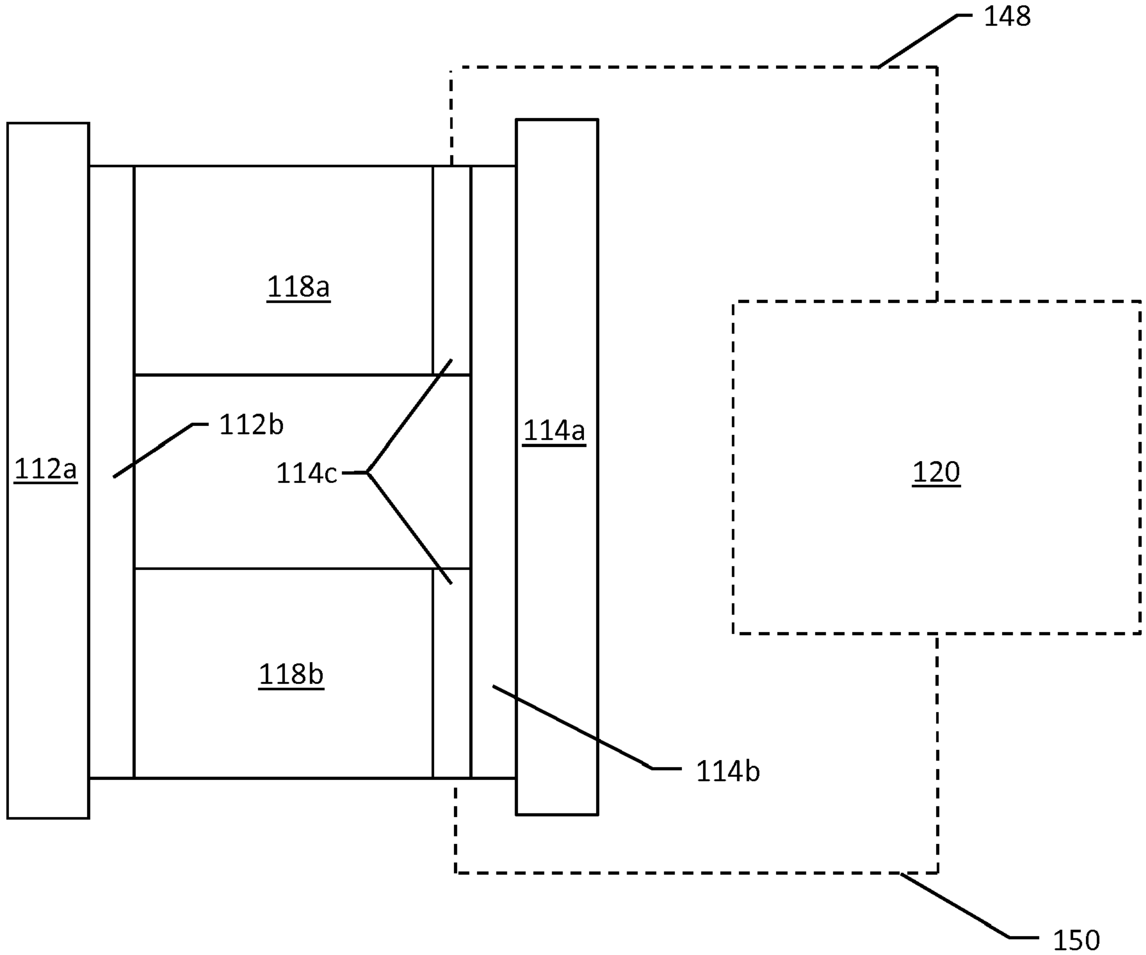

Figure 4

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EUROPEAN SEARCH REPORT

Application Number
EP 15 20 0918

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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	29 April 2016	Ott, Thomas

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
EP 15 20 0918

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The present search report has been drawn up for all claims

1

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